

# A Vision and Roadmap for Sustainable Composites



A summary of the output from a workshop on 10th January 2019 to create a shared vision of a sustainable future for composites and what is needed to get there.

February 2019

## Acknowledgements

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- All those who attended and brought their considerable experience and knowledge to the discussion



**Innovate UK**



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## Table of Abbreviations

ACMA	American Composites Manufacturers Association
AMRC	Advanced Manufacturing Research Centre, Sheffield, a HVMC centre
BEIS	Department for Business, Energy and Industrial Strategy (UK govt)
BOM	bill of materials
CAD	computer aided design
CAE	computer aided engineering
CF	carbon fibre
CFRP	carbon fibre reinforced polymer
CLF	Composites Leadership Forum, a high level body which brings together key industry stakeholders, Catapult, funding bodies and BEIS
CLF RCS WG	CLF Regulations, Codes and Standards Working Group
CLF SusWG	CLF Sustainability Working Group
CTE	coefficient of thermal expansion
EfW	energy from waste
ELV	End of Life Vehicle Directive 2000/53/EC, which requires 85% re-use / recycling and 95% re-use / recycling / recovery of vehicle parts at end of life
EOL	end of life (sometimes 'end-of-life')
EU	European Union
EuCIA	European Composites Industry Association
FRP	fibre reinforced polymer
FST	fire, smoke and toxicity
GCSC	Global Composites Sustainability Coalition
GF	glass fibre
GRP or GFRP	glass fibre reinforced polymer
HVMC	High Value Manufacturing Catapult (UK group of research and development centres including AMRC, NCC, WMG and others)
IfM	Institute for Manufacturing at the University of Cambridge
KPI	key performance indicator
KTN	Knowledge Transfer Network
LCA	life cycle assessment, typically meaning assessment of environmental impact to ISO 14044:2006
NCC	National Composites Centre, Bristol, the lead HVMC centre for composites
PAN	polyacrylonitrile, typically used as a precursor for carbon fibre
PBS	polybutylene succinate, a bio-based thermoplastic
PE	polyethylene, a widely used low cost thermoplastic
PEEK	polyether ether ketone, a high performance thermoplastic
PEF-CR	Product Environmental Footprint Category Rules, a regulatory framework under development for assessing environmental impact of products in the EU
PFA	polyfurfuryl alcohol, a bio-based resin from agricultural waste
PLA	poly lactic acid, a bio-based thermoplastic
PP	polypropylene, a widely used low cost thermoplastic
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals, EU regulation
SIG	Special Interest Group
SusWG	Sustainability Working Group
TRL	technology readiness level (on a scale of 1-9)
VOCs	volatile organic compounds
WMG	Warwick Manufacturing Group, Coventry, a HVMC centre

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## **1. Executive Summary**

The Composites UK Sustainability Subgroup and the Composites Leadership Forum Sustainability Working Group meet together as a Sustainability Working Group (SusWG) dedicated to pioneering the circular economy for fibre reinforced composites. Having identified the need for a shared vision of what success looks like and what is needed to get there, the working group committed to establishing a strategic vision and roadmap for sustainable composites to help bring focus, drive partnerships and generate new technologies to take the composites industry towards an economically, environmentally and socially sustainable future.

Thursday 10<sup>th</sup> January 2019 saw 31 professionals come together at the University of Warwick. These included manufacturers, OEMs, researchers and academics, materials suppliers, circular economy experts, waste management professionals, experts in standard development – thought leaders from across the supply chain. The University of Cambridge Institute for Manufacturing's world renowned roadmapping process was applied to develop a vision to 2040 and a landscape roadmap to achieve that vision. From this, 20 topics were selected to develop in more depth, each defining a successful future opportunity scenario, current state and path to value.

A strong vision for 2040 was developed, and a resulting vision statement has been written in draft which the SusWG will develop to reach consensus on a final version.

The landscape activity indicated that delegates expect that societal pressure and incentives to reduce waste and recycle are strong drivers which are likely to be increasingly important in the future. Consumer demand for low environmental impact solutions will continue to grow, and associated policy and legislation will develop.

Cost, as always, will remain a primary driver, though efficiencies of scale as composites break into larger markets will help. Concerns about both cost and availability of raw materials and a move away from fossil fuels will drive efficiency and use of materials and chemicals from secondary and bio-derived sources.

When votes were cast on topics, areas related to recycling and resource efficiency dominated, followed by the need for carbon and fossil fuel reduction. Some specific applications were picked out such as composites as the go to material for mobility and prefab construction.

A strong recurring theme in terms of capability needs was the development of toolsets and data for design. Data and methodology are also needed for credible and consistent life cycle assessment and to enable use of recyclate. This design data and more standardised good practice, along with improved high speed, resource and energy efficient manufacturing processes, will make us more sustainable and enable breaching of larger markets to bring the benefits of composites. Education is needed to embed design for environment principles throughout industry.

The idea of a composites passport as a means of identifying the content of products was raised in many of the topic roadmaps, as material traceability has potential to greatly improve value at end of life. We need to engage increasingly with the waste management industry for cost-effective collection and reprocessing of waste to enable circularity. The development of new chemistries will contribute to more sustainable, recyclable materials.

The 20 topic roadmaps represent opportunities to take forward specific actions. The output from this workshop will be integrated into an action plan which will be reviewed at the SusWG meetings at least bi-annually. This will be taken forward in the short term through the Knowledge Transfer Network's

Materials for Composites Special Interest Group, with an open workshop in March 2019 to build collaborations. The connections are already in place to link actions from this roadmap with High Value Manufacturing Catapult strategy, the other Composites Leadership Forum Working Groups and international trade associations.

## 2. Introduction and background

The [Composites UK Sustainability Subgroup](#)<sup>1</sup> and the [Composites Leadership Forum Sustainability Working Group](#)<sup>2</sup> meet together as a working group dedicated towards pioneering the circular economy for fibre reinforced composites. A common theme underpinning all of the excellent work undertaken in this area is that there are many different ways to contribute towards sustainability but until now there has been no shared vision of what success looks like and what is needed to get there.

In response, the Subgroup committed to establishing a strategic vision and roadmap for sustainable composites to help bring focus, drive partnerships and generate new technologies to take the composites industry towards an economically, environmentally and socially sustainable future.

The WRAP funded Resource Efficiency Action Plan (2012-2014) led into the work of the Composites Leadership Forum Sustainability Working Group (CLF SusWG) which was expressed in the [UK Composites Strategy 2016](#)<sup>3</sup>. Since then a report *Composites Recycling: Where are we now?* and an *FRP Circular Economy Study* have been carried out,<sup>4</sup> and numerous research and development and commercial activities have progressed relevant areas.

Two Knowledge Transfer Network (KTN) workshops were held in early 2018 to identify the technology needs and gaps for industrial biotechnology for composites and form a series of recommendations. These are being progressed, amongst other things, through the current KTN Materials for Composites Special Interest Group (SIG), and a collaboration building workshop on 26<sup>th</sup> March 2019 will focus directly on the findings of this report.

The CLF SusWG now meets together with members of the Composites UK Sustainability Subgroup biannually in a combined Sustainability Working Group to identify and progress strategic areas. Those invited to the vision and roadmapping workshop on 10<sup>th</sup> January 2019 included members of these groups and a selection of people with strategic knowledge in different areas related to sustainability of composites. The list of attendees is in *Appendix B*.

## 3. Roadmap process

We followed a very structured and highly disciplined approach and this can be broken down into five key stages:

1. Facilitation Pre-Work
2. Delegate Pre-Work
3. Visioning Exercise
4. Landscape Roadmap
5. Topic Roadmaps

These will be described over the following pages in order to understand the process over where we began and where we ended up.

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<sup>1</sup> <https://compositesuk.co.uk/industry-support/sub-groups/sustainability-sub-group>

<sup>2</sup> <https://compositesuk.co.uk/leadership-forum/cluster-and-working-groups/sustainability-working-group>

<sup>3</sup> <https://compositesuk.co.uk/about/industry/uk-composites-strategy>

<sup>4</sup> These can be downloaded at <https://compositesuk.co.uk/industry-support/environmental/end-life-and-recycling>

### Facilitation Pre-Work

It was decided that if we were going to ask ~35 delegates for a full day of their time, we really needed to ensure we used it wisely and generate something of value at the end of the day. For that reason, we deemed it proper to invite a professional, credible facilitator to design and run the day. The IfM (Institute for Manufacturing) at the University of Cambridge were chosen for the task due to their strong credentials in strategic and technical roadmapping consultancy services.

Bill Colquhoun (IfM), Stella Job (Composites UK) and Steven Brown (Scott Bader Company Ltd) engaged in a number of teleconferences to define the *Scope, Objective & Deliverables* of the workshop, how it could be achieved and how we should engage across the UK composites industry. This included agreeing upon the timescales for the roadmap, building the taxonomy for the landscape roadmap (the words, phrases and text on the landscape roadmap to support the **Trends & Drivers**, the **Value Opportunities** and the **Capabilities** – see Appendix C:) and also a few vision statements of what a sustainable composites industry must aspire to deliver. All of this was pulled together in a delegate pre-pack and sent out a month in advance of the event.

### Delegate Pre-Work

In order to get the best value from the day it was important to ensure the delegates were primed and ready to hit the ground running on the morning of the event. To enable this, each delegate was asked to complete some “homework” in advance of the event which involved them considering the following:

- Consider the customers, the suppliers, the competitors, government policies, social pressures etc that are driving a need for sustainable composites
- Consider what the application, the product or the service perspective looks like that satisfies this need
- Consider what capabilities in science, technology and resources we need to develop in order to deliver these applications, products or services

The delegates were asked to send their completed pre-work back to the Bill where it was collated and included in the delegate pack (see Appendix G:).

### Visioning Exercise

For the visioning exercise, the delegates were asked to envisage a future where the environment consists of:

- A world that is cleaner and healthier now and for future generations
- A growing population and consumer aspirations puts increasing demand on the planet’s resources
- The composites industry is looking at adjacent markets, geographies and technologies for new opportunities
- New raw materials, fibres and matrices will impact future new applications
- New modes of transportation will change material needs and business models

In tables of around 5-6 people they were asked to come up with (i) **Drivers/Markets**, (ii) **Sustainable Applications** (iii) **Capabilities** that develop along the path from today to the future. This was done on post-it notes and added to a matrix (see Appendix C:) according to what table they belonged to which, upon completion formed the basis of our shared vision for a sustainable composites industry. The delegates were then given three votes and asked to indicate which group had given the best vision of the future. The overall vision was then decided and communicated to the audience.

### Landscape Roadmap

Having communicated the shared vision for 2040, the group were then asked to consider the implications of that and to produce value stream ideas for opportunities that the vision may suggest. The ideas had to be supported by one (or more) drivers and one (or more) capabilities required to deliver the idea. This was done on post-it notes and the “strip of ideas” was added to the landscape roadmap (see Appendix C:) in line with the timescale and the relevant position in the swim-lanes. Once completed, the delegates were asked to vote on their favourite applications – each delegate was given three votes which they could use as they see fit.

### Topic Roadmaps

The top 20 applications from the landscape roadmap were brought forward to develop 20 topic roadmaps. To achieve this it was necessary to run the topic roadmaps over two sessions of one hour each.

For each session, teams of 3-4 were chosen and assigned to a topic that it was thought they could best contribute towards – this was decided by Stella and Steven. Each team was then given a topic roadmap template (see Appendix C:) and asked to do three things:

1. Define the successful future value opportunity scenario including **what** it is, **why** it is needed and **how** we achieve it
2. Define the current state of applications with respect to the topic, the current trends/drivers and our current capabilities
3. Define a core path to get from our current state to our future value opportunities i.e. the stepping stones taking into account the **what, whom, when, how, where** and **why**?

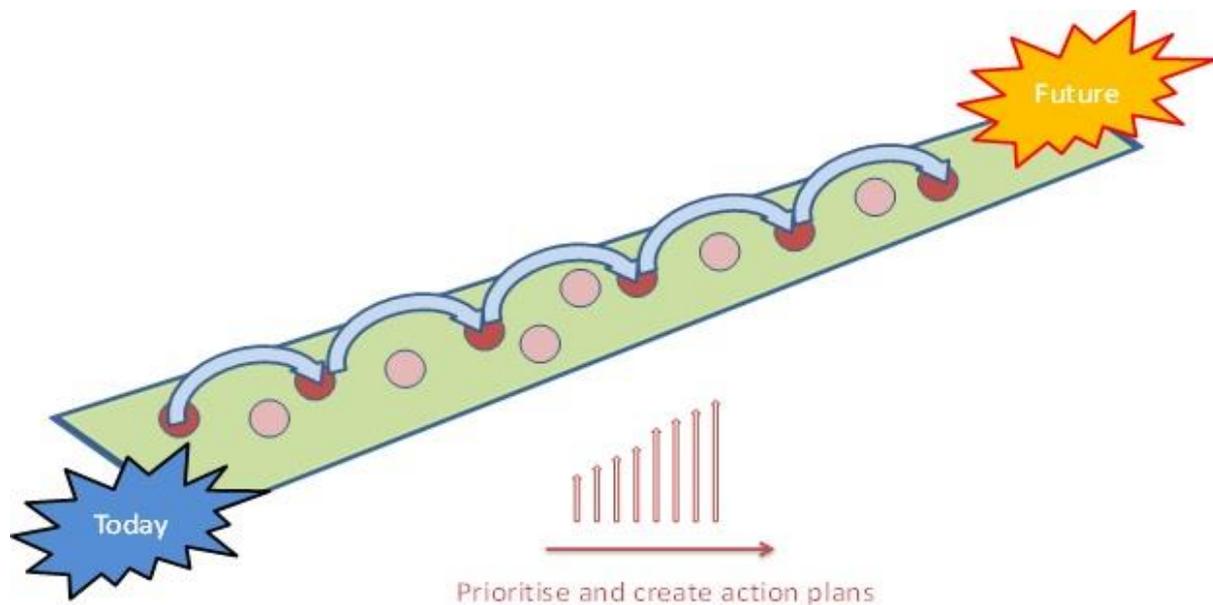


Figure 1: Backcasting from future to present including key steps/ideas along the way

## **4. Vision Statement (draft)**

The full list of comments from all groups during the vision exercise is listed in Appendix D:. This resulted in an aligned vision which has been summarised in prose as below. The Composites UK Sustainability WG will work on a final version of this.

In 2040 we envision a future where ultra-light weight, high performance composite products and durable, repairable composite structures contribute to a sustainable environment, sustainable society and sustainable economy.

Zero or negative CO<sub>2</sub> composite manufacturing will no longer use virgin petrochemicals, will turn waste back into raw materials and will have predominantly local material supply chains, reducing our impact on the planet for our generation and all future generations.

In 2040 the drive to limit climate change will be paramount. Environmental life cycle assessment will be required for all products. Furthermore, the consumers, manufacturers and decision makers in 2040 will be increasingly incentivised by sustainability factors rather than purely financial ones. Landfilling of waste will no longer be an option, whether due to cost or legislation, and manufacturers will have ownership of, and responsibility for, their products at their end of life. This will help develop business models based on leasing, rather than ownership, a paradigm shift which could profoundly affect our industry.

Underpinning our industry, we will have developed the data, methodology and standards to assess life cycle impact effectively and consistently in a global marketplace. Publicly available engineering design data will be in place to enable wider adoption of composites. Products will be designed to be disassembled and incorporate raw material traceability, enabling re-use or recycling at end of life.

Development and capital investment will have led to mature supply chains for bio-based and re-cycled / recovered raw materials. Systems will be in place to match waste sources with potential users, and process support will be available to manufacturers to incorporate scrap in products. Overall, manufacture will have zero waste and zero or negative energy consumption.

## 5. Landscape roadmap and priorities

The Landscape Roadmap exercise resulted in around 30 ‘Sustainable Value Opportunities’ linked to ‘Trends and Drivers’ and underpinned by ‘Capabilities’. The resulting chart was complex.

Post-it notes on the chart were linked by group / idea references. These are listed in full, with the associated ‘Trends and Drivers’ and ‘Capabilities’ adjacent to the relevant opportunity idea, in Appendix E:.

### Trends and Drivers

The trends and drivers expected to influence development are broadly grouped and summarised as shown in Figure 2 (in some cases one post-it note has been given points in each of two different categories).

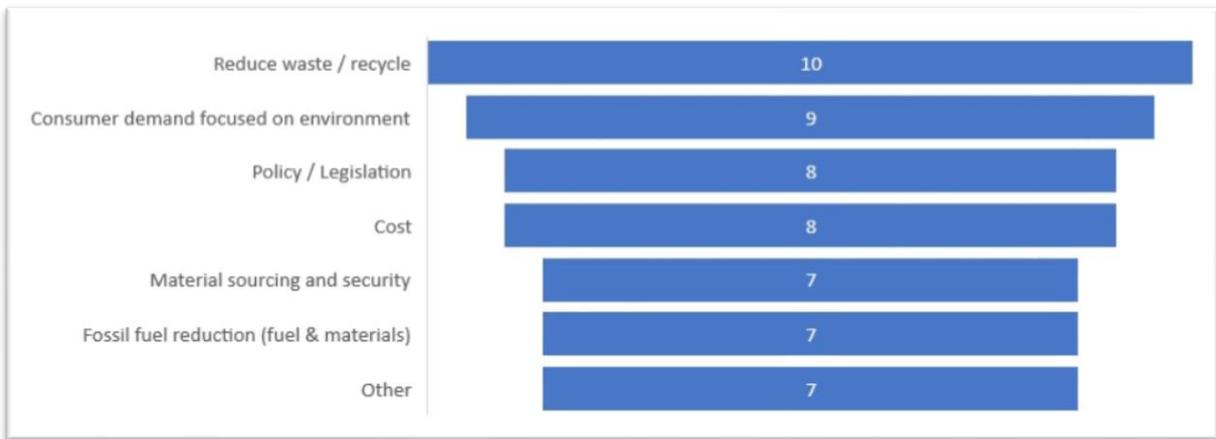


Figure 2: Expected trends and drivers and number of occurrences in landscape roadmap exercise

This indicates that delegates expect that societal pressure and incentives to reduce waste and recycle, along with the cost of waste management and lack of landfill space, are strong drivers which are likely to be increasingly important in the future. The trend is that consumer demand for low environmental impact solutions will continue to grow, and associated policy and legislation will develop to limit emissions and landfill, requiring ownership of end-of-life (EOL) materials and an expectation for well-defined, credible and industry-supported life cycle impact assessments.

Cost, as always, will remain a primary driver, including increased costs of waste management, regulatory requirements and cost of virgin raw materials, though efficiencies of scale as composites break into larger markets will help. Concerns about both cost and availability of raw materials will drive efficiency and use of materials from secondary or alternative sources. A move away from fossil fuels will open up opportunities for sustainably sourced chemicals.

Other drivers may include increasing the range of electric vehicles, health risks of toxic chemicals and loss of skilled labour.

### **Sustainable Value Opportunities**

Votes were cast on the 'Sustainable Value Opportunities' in the middle swim lane. Subjects for the topic roadmaps were chosen based on these.

Priorities based on the voting for the main topics can be summarised as follows (no of votes in brackets):

- Areas related to recycling and resource efficiency (almost half of votes cast):
  - 100% recycled and recyclable composite parts (11)
  - repurpose manufacturing waste back into process (6)
  - composite materials passport (6)
  - design for disassembly and value recovery / re-use (5)
  - circular business models (5)
  - develop options for end of life (4)
  - no landfill for waste composites (3)
  - develop different applications for recovered material (2)
  - zero waste / zero tooling manufacture (2)
  
- Carbon and fossil fuel reduction:
  - carbon negative composites (6)
  - no fossil fuel derived ingredients - all applications (5)
  - cost effective bio-based thermoplastic (5)
  - increase % of sustainable feedstock (4)
  
- Enabling composites for specific applications:
  - composites as go to material for mobility (8)
  - prefab construction (4)
  
- Design capability (arguably this should be in capabilities rather than opportunities):
  - design for disassembly and value recovery / re-use (5) (as above)
  - sustainable composite design (3)
  
- Hybrid smart, multifunctional multimaterials (5)

### **Capability**

In terms of capability needed to achieve the opportunities, particular recurring themes included:

- Established toolsets and data for design, for LCA and to enable use of recyclate
- Cost effective collection and reprocessing of waste
- Improved manufacturing processes including digital, analytics, sensors
- Developing new chemistries, materials science
- Traceability / ID markers / 'passport'
- Education for design for sustainability, disassembly, etc

## **6. Topic roadmaps**

The 20 topic roadmaps addressed are listed below. A description of each of these is included in Appendix F:. These may represent different understandings or opinions. However, they represent opportunities to take forward specific actions which we are keen to see developed.

(Click a title below to go directly to the description in Appendix F:.)

### **Session A**

- A1: Carbon negative composites
- A2: Establish bio and secondary resource supply chain
- A3: Eliminating the use of toxic/hazardous raw materials for fire retardant applications
- A4: Composite materials passport
- A5: No landfill for waste composites
- A6: Circular economy business models
- A7: 100% recycled, 100% recyclable composite parts
- A8: Increase % of sustainable feedstock
- A9: Hybrid smart, multifunctional multimaterials
- A10: Composites as go to material for mobility

### **Session B**

- B1: No unsustainable fossil fuel derived ingredients
- B2: Repurpose manufacturing waste back into process
- B3: Develop applications for recovered material
- B4: Prefab construction
- B5: Zero waste, zero tooling manufacture
- B6: Value chain based on rented / leased composite materials
- B7: Cost-effective bio-based thermoplastic
- B8: Developing new / emerging recycling technologies
- B9: Design for sustainability
- B10: Design for disassembly and value recovery / reuse

## **7. Next Steps**

### **Collaboration building**

The KTN Materials for Composites SIG workshop planned for 26<sup>th</sup> March 2019 provides an excellent opportunity to bring together collaborations to develop some of the topic roadmaps identified. The continued activities of the SIG in 2019 will provide further opportunities. Beyond the SIG (which ends September 2019), the CLF will continue to hold occasional collaboration events in key areas, and events run and supported by Composites UK provide ongoing opportunities to disseminate progress and enable collaborations.

### **Standards**

The landscape and topic roadmaps identified the need for appropriate standards to support:

- Development of specific product types
- Use of recycled and bio-based raw materials which may not currently have standards by which they can be specified
- Life cycle assessment methodologies and data

The CLF SusWG will continue to coordinate with the CLF Regulations, Codes and Standards (RCS) working group, which has an ongoing roadmap to clearly identify and fill the gaps in the needs for standards for composites. Graham Sims chairs the CLF RCS WG and also sits on the CLF SusWG and attended the workshop.

### **Data and design**

A challenging area is the need for underpinning capability in design which takes into account disassembly, recyclability, sustainable material content and resource and energy efficient processing. There is a critical need for education to embed design for environment principles throughout industry. The lack of openly available design data for even commonly used raw materials and composites limits expansion into new markets, and more is needed to cover secondary and alternatively sourced materials.

### **HVMC and CLF alignment**

The outcome of this workshop is being discussed with members of the High Value Manufacturing Catapult (HVMC) Circular Economy Strategy Team in order to align Composites UK activities with the HVMC strategy and roadmap, and provide industry direction to HVMC priorities. It is also linked with the Composites Leadership Forum and will be shared with the chairs of the other CLF WGs.

It is hoped that it will be possible to integrate the roadmaps / action plans of the CLF WGs through suitable software, providing more effective tracking of activities and accountability to industry. However, this is dependent on funding for a CLF coordinator.

### **International collaboration**

It is vital to develop our activities in a global context, enabling global trade and knowledge exchange. Composites UK is a member of, and is working actively with, the European Composites Industry Association (EuCIA) and the American Composites Manufacturers Association (ACMA) to share knowledge and progress common areas. The Global Composites Sustainability Coalition meets at the JEC and CAMX exhibitions each year to facilitate this. Composites UK is active in the EuCIA Sustainability Group in areas related to recycling and Composites UK and the National Composites Centre are committed to supporting the development of EuCIA's EcoCalculator LCA tool for composites. EuCIA is actively involved in development of standards such as the Product Environmental Footprint Category Rules (PEF-CR) and Circular Plastics initiatives in Brussels.

### **Action plan**

The output from this workshop will be integrated into an action plan, which will be reviewed at Sustainability WG meetings at least bi-annually and feed into the Composites Leadership Forum activities.

We aim to reach consensus on a succinct version of the Vision. The topic roadmaps need to be assessed to understand the overlaps, priorities and timelines, and linking to the overarching drivers and underpinning capability requirements. This could be done using software such as [the Brain](#).<sup>5</sup> This will lead to an action plan where specific sub-projects can be identified with estimated costs and delivery partners, including identifying who we need to reach out to who is not currently part of our network.

This will be an ongoing process and needs to be harmonised with other activities, especially the CLF working groups and HVMC.

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<sup>5</sup> <https://www.thebrain.com/>

## **Appendix A: Workshop agenda**

For the workshop on Thursday 10<sup>th</sup> January 2019 at Scarman, University of Warwick

08.30	Arrival, coffee and registration
09.00	Introduction
09.15	Workshop process and agenda
09.30	Vision exercise
10.30	Break
10.45	Landscape Roadmap session
12.30	Prioritise the value stream ideas
13.00	Lunch
13.45	Topic Roadmap deep dives – session 1
14.45	Break
15.00	Topic Roadmap deep dives – session 2
16.00	Review of Topic Roadmaps and feedback session
16.45	Round up and review of next steps
17.00	Close

## Appendix B: Workshop attendees

Firstname	Lastname	Title	Organisation
Steve	Barbour	Managing Director	Composite Braiding Ltd
Frazer	Barnes	Managing Director	ELG Carbon Fibre
Olivia	Bertham	Senior Consultant	Oakdene Hollins
<b>Steven</b>	<b>Brown</b>	<b>Technology Development Manager Chair of Composites UK Sustainability Subgroup</b>	<b>Scott Bader Company Ltd</b>
Joe	Carruthers	Managing Director	Composites Evolution Ltd
Andy	Clifton	Global Sustainability Mgr – Eng & Design <i>Chair ADS Design for Environment WG</i>	Rolls-Royce
Stuart	Coles	Associate Professor	WMG, University of Warwick
<b>Bill</b>	<b>Colquhoun</b>	<b>Principal Industrial Fellow Workshop Facilitator</b>	<b>IfM ECS Ltd</b>
John	Conti-Ramsden	Director of the Knowledge Centre for Materials Chemistry	Centre for Process Innovation
Richard	Diskin	Process Development Engineer	CUBIS Systems
Natan	Elfassy	Business Development Manager	Agecko UK Ltd
Steve	Fletcher	Head of Chemistry & Industrial Biotechnology	KTN
Malcolm	Forsyth	Director, Global Strategy	Scott Bader Company Ltd
Bharat	Gandhi	Quality/Environmental Systems Manager	Filon Products Limited
Peter	Garrett	Senior Specialist, Global QSE	Vestas
Marcus	Henry	Research Manager	Jaguar Land Rover
Sheena	Hindocha	KTM Materials Chemistry	KTN
<b>Stella</b>	<b>Job</b>	<b>Supply Chain and Environment Manager Chair of CLF Sustainability WG</b>	<b>Composites UK</b>
Nigel	Keen	Business Development Engineer	National Composites Centre
<b>Diana</b>	<b>Khripko</b>	<b>Solution Development Specialist</b>	<b>IfM ECS Ltd</b>
Gary	Leeke	Professor of Chemical Engineering	University of Birmingham
Paul	McCutchion	Commercial Manager, CALMARE	University of Exeter
John	McQuilliam	Chief Engineer	Prodrive
Steve	Newman	Materials Engineer	Vestas
Lien	Ngo	Innovation Lead - Advanced Materials	Innovate UK
Steve	Pickering	Hives Professor of Mechanical Engineering	University of Nottingham
Graham	Sims	NPL Fellow (Composites)	National Physical Laboratory
Tim	Sweatman	Managing Director	Eco-Composites
Jaap	van der Woude	Chair of Sustainability Group	EuCIA
Clive	Williams	Group Polymer Development Manager	Scott Bader Company Ltd
Peter	Wilson	Post Doctoral Research Fellow	WMG, University of Warwick
Martin	Wright	Sales Manager, Northern European Zone	Polynt Composites EMEA
Tim	Young	Advanced Market Development Engineer	National Composites Centre

(bold = facilitator / organiser):

## Appendix C: Workshop templates

### Prewrite Template

# 2040 Vision Perspectives

Descriptions	Here is an example of what we mean to allow you to add your own ideas in the last column	Please add your examples below one per box
Drivers + Market (customers/competitors) + Business perspective	The UK economy has a drive for increasing self sufficiency	Add here
Sustainable Application, Product/Service perspective	More secure supply chain through the use of sustainably (bio) derived materials	Add here
Capabilities, Science and Technology Resource perspective	For example, Hemp exports could be diverted to providing a useful source of fibre and lignocellulose	Add here

### Vision

### Vision

### Template

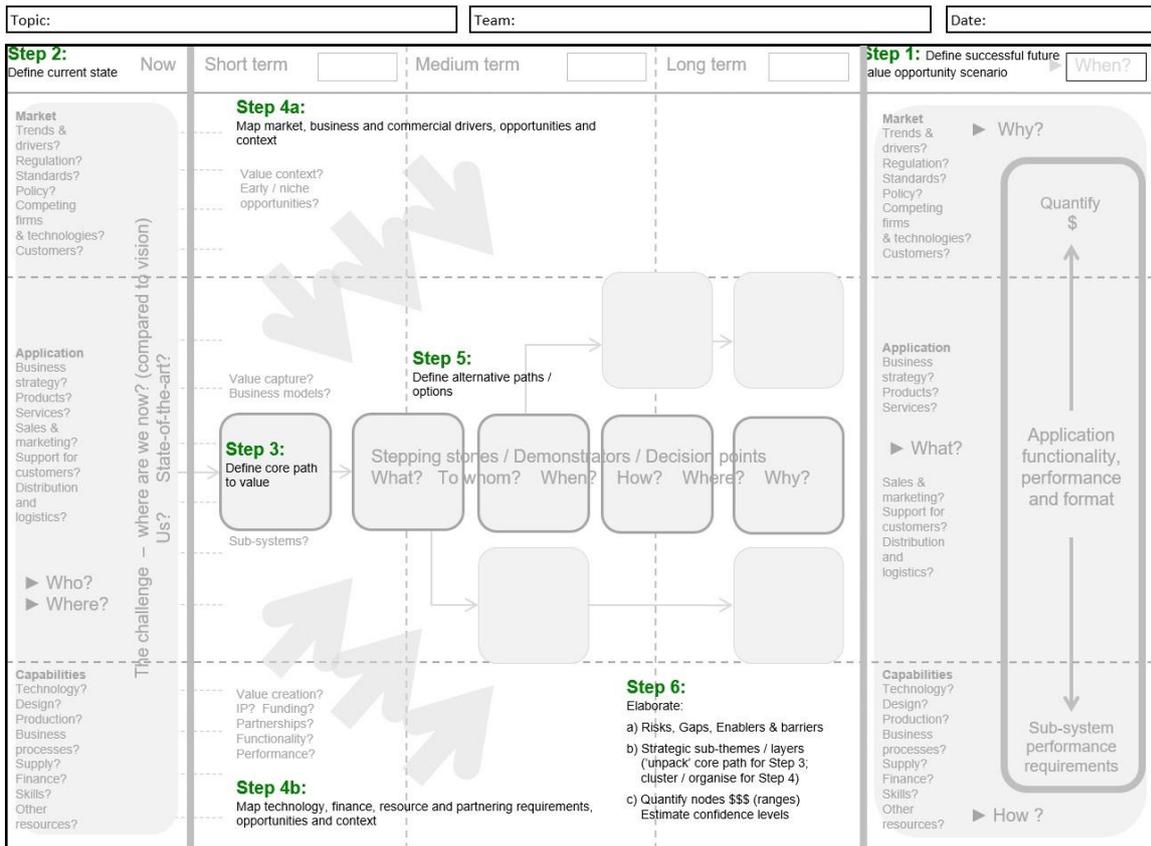
For each of the different groups, what are the key concepts that must be clearly articulated in the vision of the future?

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	An aligned vision of the future
Drivers + Market (customers/competitors) + Business perspective							
Sustainable Applications, Product/Service perspective							
Capabilities, Science and Technology Resource perspective							

**Landscape Roadmap template**

		2019	Short Term	2022	2023	Medium Term	2030	2030	Long Term	2040
<b>Trends &amp; Drivers</b>	Key Mega Trends e.g. Technologies, Environmental and Regulatory, Materials, Economics									
	Key Market Sector Opportunities									
	Key Stakeholder Sustainability Drivers									
	Competitor Threats									
	Other									
<b>Sustainable Value Opportunities</b>	Raw Material sustainability improvements									
	Manufacturing sustainability improvements (Energy, HSE, Toxicity, Waste)									
	In-service application sustainability improvements									
	Post life processes and application improvements									
	Other									
<b>Capabilities</b>	Capabilities Examples R&D, Supply chain design and operation, Waste management, Knowledge Skills (LCA) Training, Regulations, Standards and Codes management									
	Technologies Examples New raw materials, Recycling									
	Other									

**Topic Roadmap template**



## Appendix D: Vision spreadsheet

Typed up version of the completed Vision template, with aligned vision summarised after voting.

	Aligned Vision	Table 1	Table 2	Table 3	Table 4	Table 5	Table 6
<b>People</b>	(influenced by votes not shown here)	<b>Steven Brown</b> <i>Scott Bader Company Ltd</i> <b>Gary Leeke</b> <i>University of Birmingham</i> <b>Natan Elfassy</b> <i>Agecko UK Ltd</i> <b>Sheena Hindocha</b> <i>KTN</i> <b>Peter Garrett</b> <i>Vestas</i>	<b>Stella Job</b> <i>Composites UK</i> <b>Tim Young</b> <i>National Composites Centre</i> <b>Marcus Henry</b> <i>Jaguar Land Rover</i> <b>Steve Barbour</b> <i>Composite Braiding Ltd</i> <b>Martin Wright</b> <i>Polynt Composites EMEA</i>	<b>Nigel Keen</b> <i>National Composites Centre</i> <b>Malcolm Forsyth</b> <i>Scott Bader Company Ltd</i> <b>Richard Diskin</b> <i>CUBIS Systems</i> <b>John McQuilliam</b> <i>Prodrive</i> <b>Stuart Coles, WMG,</b> <i>University of Warwick</i>	<b>Joe Carruthers,</b> <i>Composites Evolution Ltd</i> <b>Steve Pickering,</b> <i>University of Nottingham</i> <b>Olivia Bertham</b> <i>Oakdene Hollins</i> <b>Bharat Gandhi</b> <i>Filon Products Limited</i> <b>Steve Fletcher</b> <i>KTN</i>	<b>Paul McCutcheon</b> <i>University of Exeter</i> <b>Clive Williams</b> <i>Scott Bader Company Ltd</i> <b>Graham Sims</b> <i>National Physical Lab</i> <b>Steve Newman</b> <i>Vestas</i> <b>Frazer Barnes</b> <i>ELG Carbon Fibre</i>	<b>John Conti-Ramsden</b> <i>CPI</i> <b>Tim Sweatman</b> <i>Eco-Composites Ltd</i> <b>Jaap van der Woude</b> <i>EuCIA</i> <b>Andy Clifton</b> <i>Rolls-Royce</i> <b>Lien Ngo</b> <i>Innovate UK</i>
<b>Drivers</b>	Climate mitigation to 1.5C	Climate mitigation to 1.5C	sustainable end use	increasing cost of finite resources, e.g. fossil fuels	legislation / economics limiting climate change	cost of materials (virgin materials)	Human drive for novelty - drive for experience of other things
	LCA impact required for products	Consumer purchasing ethics trend increasing	sustainable feedstocks	increasing cost of non-recycling disposal options		lack of hydrocarbons	economic sustainability
	Consumers / manufacturers / decision makers with increasing ethics	Driving up landfill costs plus perception risks	LCA impact for whole life required	consumer demand for more bio / natural materials		populist activism	decarbonisation goals, IPCC, etc
	Increasing cost and/or bans on landfilling of waste		availability / cost of oil prohibitive raw materials	increasing recognition of the negative impacts of climate change		consumer driven	material sustainability in full life cycle
	Manufacturer ownership of products at end of life		2040 demand for urban transport will have radically changed. Rent and recycle	market / consumer rejection of single use plastics		worldwide and govt legislation	
	Lease vs ownership paradigm shift			changing needs / desires for transport - more shared, more fuel efficient			

<b>Applications</b>	No more virgin petrochemicals in composites	Better supply chain for bio-derived materials	automotive vehicle structures 2M/year, 1500kg	manufacture recyclable automotive parts from recycled fibres	all composites have another use... and another...	construction	transport - auto plus aero
	Waste back into raw materials	local supply chains	durability and performance and performance reqts for large engineering structures	products with high level of reclaimed raw materials from end of life composites	composites are go to material for mobility	electronics	construction plus big scale structures
	Local supply chain for raw materials	zero CO2 manufacture		100% bio-derived composite products	carbon negative composites	transportation	consumer goods
	Zero CO2 manufacture	waste back into raw materials		ultra light weight high performance composites	no more virgin petrochemicals in composites by 2040	renewable energy	
	Durable and repairable structures						
	Ultra light weight high performance composites				clear pathways for different composite options based on LCA		
<b>Capabilities</b>	LCA data, methodology plus standards	Carbon capture at low cost	UK engineering material datasets to enable adoption	improve composite design knowledge plus LCA	Better LCA application	traceability	logistics for handling end of life
	Development plus capex for biochemicals	Traceability plus standards for waste materials	market for end of use composites	increased multiple usage of recycled composite materials	decarbonise the production process > carbon neutral composites	logistics / collection	design for sustainability
	Matching waste sources with potential users, with process support, for the re-use of scrap	zero waste manufacture	freely available design data - performance, cost, sustainability	enhancing bio-derived resins		degradation - chemical + bio	decarbonisation of materials
	Design for disassembly	flexible approach to react to policy / drivers	UK based supply chains-raw material, tooling, testing, recycling	enhancing bio-derived fibre		separation of materials / techniques	
	Traceability of raw materials and products at end of life	easy disassembly of composites parts and materials		increased inter-connectivity between value chains to allow material exchange		development of second stage material use	
	Manufacture zero waste and zero / negative energy consumption			increased LCA capability -increasing knowledge and decreasing assumptions			
	Engineering data to enable wider adoption						

## Appendix E: Landscape Roadmap analysis

Post-it notes on the chart were linked by group / idea references. Votes were cast only on the middle swim lane – ‘Sustainable Value Opportunities’. These are listed below, with the associated ‘Trends and Drivers’ and ‘Capabilities’ adjacent to the relevant opportunity idea. Subjects for the topic roadmaps were chosen based on the ‘Sustainable Value Opportunities’ and the votes cast.

		Group	Idea	Votes	Term
<b>Capabilities</b>	hub / group to drive and manage	1	2		Medium
<b>Trends and Drivers</b>	gov policies on emissions and landfill	1	3		Medium
<b>Sustainable Value Opportunities</b>	enabler to allow research to generate waste solutions	1	3	1	Medium
<b>Capabilities</b>	recovered raw material with cost parity (or benefits) to virgin	1	3		Medium
<b>Capabilities</b>	development of cost-effective collection and reprocessing	1	3		Medium
<b>Sustainable Value Opportunities</b>	developed bio and secondary resource supply chain	1	4	0	Long
<b>Capabilities</b>	data / reporting: LCA; KPIs; disclosure	1	4		Long
<b>Sustainable Value Opportunities</b>	design for disassembly and value recovery / re-use	1	6	5	Long
<b>Sustainable Value Opportunities</b>	lightweight transportation vehicles (min 75% composite w/w)	1	6	0	Long
<b>Capabilities</b>	engine efficiency and zero emissions	1	6		Long
<b>Trends and Drivers</b>	restoration vs sustainability	1	7		Long
<b>Sustainable Value Opportunities</b>	carbon offset by making bio from fossil carbon	1	7	0	Long
<b>Capabilities</b>	take examples of CO2 being used to grow crops and apply to fibres, i.e. hemp - establish new value chains	1	7		Long
<b>Trends and Drivers</b>	problems of recycling	2	1		Short
<b>Trends and Drivers</b>	potential health risk	2	1		Short
<b>Trends and Drivers</b>	standardised LCA data regulated and available	2	1		Medium
<b>Sustainable Value Opportunities</b>	eliminating the use of halogenated FRs	2	1	1	Medium
<b>Capabilities</b>	develop new chemistry	2	1		Medium
<b>Trends and Drivers</b>	cost of virgin raw materials	2	2		Short
<b>Trends and Drivers</b>	cost of waste management	2	2		Short
<b>Trends and Drivers</b>	public pressure to reduce waste	2	2		Short
<b>Sustainable Value Opportunities</b>	develop options for end of life	2	2	4	Medium
<b>Capabilities</b>	increased lifespan > repair tech + durable composites	2	2		Medium
<b>Capabilities</b>	established toolsets and data, inc LCA	2	2		Medium
<b>Capabilities</b>	design for re-use	2	2		Medium
<b>Capabilities</b>	eBOM (bill of materials) / industry 4.0 (relates to passport idea of G4)	2	2		Long
<b>Capabilities</b>	develop new technology	2	2		Long
<b>Sustainable Value Opportunities</b>	develop different applications for recovered material	2	3	2	Short

<b>Capabilities</b>	acceptance of re-used materials plus data to support	2	3		Short
<b>Trends and Drivers</b>	downsizing now very expensive, especially WT blades	2	4		Short
<b>Sustainable Value Opportunities</b>	downsizing of large / thick structures	2	4	0	Short
<b>Capabilities</b>	efficient supply chain / collection / equipment	2	4		Short
<b>Trends and Drivers</b>	move away from fossil fuel derived chemicals	2	4		Medium
<b>Trends and Drivers</b>	balance CO2 effect of incineration	2	4		Medium
<b>Sustainable Value Opportunities</b>	increase % of sustainable feedstock	2	4	4	Medium
<b>Capabilities</b>	legislative change to drive sustainably sourced materials	2	4		Medium
<b>Capabilities</b>	develop new chemistries and sustainable source / viable source	2	4		Long
<b>Trends and Drivers</b>	cost/business uptake and legislation	2	5		Short
<b>Sustainable Value Opportunities</b>	repurpose manufacturing waste back into process	2	5	6	Short
<b>Capabilities</b>	improved design and manufacturing methods	2	5		Short
<b>Trends and Drivers</b>	legislation (ELV+)	3	1		Medium
<b>Trends and Drivers</b>	sales and attraction of using more benign raw materials	3	1		Medium
<b>Trends and Drivers</b>	consumer choice	3	1		Medium
<b>Trends and Drivers</b>	incentivised recycled content	3	1		Medium
<b>Trends and Drivers</b>	reduced cost of product	3	1		Medium
<b>Sustainable Value Opportunities</b>	100% recycled and recyclable composite parts	3	1	11	Medium
<b>Capabilities</b>	robust data on recycled materials	3	1		Medium
<b>Capabilities</b>	lobbying and public engagement	3	1		Medium
<b>Capabilities</b>	understanding processing of recycled feedstocks	3	1		Medium
<b>Capabilities</b>	availability of recycled feedstocks at scale	3	1		Medium
<b>Capabilities</b>	demonstrator parts	3	1		Medium
<b>Trends and Drivers</b>	reduction in use of virgin materials	3	4		Short
<b>Trends and Drivers</b>	reduced cost / timeline to first part	3	4		Short
<b>Sustainable Value Opportunities</b>	sustainable tooling for composite manufacturing	3	4	1	Short
<b>Capabilities</b>	thermoplastic tooling solutions	3	4		Short
<b>Trends and Drivers</b>	legislation on ownership	3	6		Long
<b>Trends and Drivers</b>	consumer preference - rent not own	3	6		Long
<b>Sustainable Value Opportunities</b>	value chain based on rented composite materials	3	6	1	Long
<b>Capabilities</b>	developed circular economy routes - takeback, etc	3	6		Long
<b>Capabilities</b>	vertical integration or collaboration in supply chain	3	6		Long
<b>Capabilities</b>	altering supply chain mindset	3	6		Long
<b>Capabilities</b>	standard industry KPIs	4	1		Short
<b>Trends and Drivers</b>	carbon reduction agenda; changing public perception	4	1		Long

<b>Sustainable Value Opportunities</b>	carbon negative composites	4	1	6	Long
<b>Capabilities</b>	carbon negative ingredients for composites	4	1		Long
<b>Trends and Drivers</b>	lack of landfill space and retaining valuable resources	4	2		Short
<b>Trends and Drivers</b>	legislation / financial driver	4	2		Short
<b>Sustainable Value Opportunities</b>	no landfill for waste composite	4	2	3	Short
<b>Capabilities</b>	waste gathering, identification, sorting processes	4	2		Short
<b>Capabilities</b>	zero waste recycling processes	4	2		Short
<b>Trends and Drivers</b>	ability to recycle, industry / social pressure	4	2		Medium
<b>Capabilities</b>	Id markers; scanner / barcode system; IOT	4	2		Medium
<b>Sustainable Value Opportunities</b>	composite materials passport	4	3	6	Medium
<b>Trends and Drivers</b>	customer pressure / legislation	4	4		Medium
<b>Sustainable Value Opportunities</b>	no fossil fuel derived ingredients - all applications	4	4	5	Medium
<b>Capabilities</b>	viable alternative; improved secondary raw materials	4	4		Medium
<b>Trends and Drivers</b>	carbon reduction agenda; renewable fuel sources	4	5		Long
<b>Trends and Drivers</b>	electric vehicle range	4	5		Long
<b>Sustainable Value Opportunities</b>	composites as go to material for mobility	4	5	8	Long
<b>Capabilities</b>	higher volume and lower cost	4	5		Long
<b>Trends and Drivers</b>	recyclability	5	1		Short
<b>Trends and Drivers</b>	reduction in fossil fuel requirements	5	1		Short
<b>Sustainable Value Opportunities</b>	cost effective bio-based thermoplastic	5	1	5	Short
<b>Capabilities</b>	manufacturing processes - new materials - finished parts	5	1		Short
<b>Capabilities</b>	traceability + standardisation	5	1		Short
<b>Capabilities</b>	material science - formulation	5	1		Short
<b>Trends and Drivers</b>	environmental pressures	5	2		Short
<b>Trends and Drivers</b>	reduction in use of primary raw materials	5	2		Short
<b>Trends and Drivers</b>	reduction in fossil fuel	5	2		Short
<b>Sustainable Value Opportunities</b>	improved decarbonisation process	5	2	1	Medium
<b>Capabilities</b>	recyclable resins	5	2		Medium
<b>Capabilities</b>	carbon capture resins	5	2		Long
<b>Trends and Drivers</b>	circular economy	5	3		Short
<b>Trends and Drivers</b>	lower impact	5	3		Short
<b>Sustainable Value Opportunities</b>	sustainable composite design	5	3	3	Short
<b>Capabilities</b>	traceability + standardisation	5	3		Short
<b>Capabilities</b>	new design approaches - modular design for extended life	5	3		Short
<b>Capabilities</b>	training / education sustainable design	5	3		Short
<b>Capabilities</b>	design for disassembly	5	3		Short

<b>Capabilities</b>	condition monitoring	5	3		Short
<b>Trends and Drivers</b>	zero waste	5	4		Medium
<b>Sustainable Value Opportunities</b>	zero waste / zero tooling manufacture	5	4	2	Medium
<b>Capabilities</b>	digital manufacture	5	4		Medium
<b>Trends and Drivers</b>	new sources of raw materials	5			Short
<b>Trends and Drivers</b>	efficiencies of scale	6	1		Short
<b>Trends and Drivers</b>	expansion of markets	6	1		Short
<b>Sustainable Value Opportunities</b>	large structure manufacture	6	1	1	Short
<b>Trends and Drivers</b>	efficiency + capacity of construction for population change	6	2		Medium
<b>Trends and Drivers</b>	loss of skilled labour	6	2		Medium
<b>Sustainable Value Opportunities</b>	prefab construction	6	2	4	Medium
<b>Capabilities</b>	joining and de-joining technology	6	2		Medium
<b>Trends and Drivers</b>	modularity	6	3		Long
<b>Trends and Drivers</b>	ease of repair	6	3		Long
<b>Sustainable Value Opportunities</b>	hybrid smart, multifunctional multimaterials	6	3	5	Long
<b>Capabilities</b>	recycling of mixed materials	6	3		Long
<b>Capabilities</b>	analytics and sensors	6	3		Long
<b>Trends and Drivers</b>	material efficiency	6	5		Short
<b>Trends and Drivers</b>	security of supply	6	5		Short
<b>Sustainable Value Opportunities</b>	circular business models	6	5	5	Short
<b>Capabilities</b>	data	6	5		Short

## Appendix F: Topic Roadmaps

### A1: Carbon negative composites

*Clive Williams, Scott Bader Company Ltd*

*Richard Diskin, CUBIS Systems*

*Peter Wilson, WMG*

#### Future Scenario

In 2040, there will be a carbon tax on all products which has driven, and maintained, research, development and manufacture of composite products to low and then net negative carbon generation, in the form of CO<sub>2</sub>. This tax has been a result of ambitious targets set by the UN and applied globally.

Net negative carbon has been achieved through new low energy production methods of carbon fibre, the use of bioderived resins, improved natural fibres and greater use of reclaimed raw materials. As natural raw materials sequester CO<sub>2</sub> from the atmosphere during their growth, this has helped achieve these ambitious UN targets. Furthermore, improved LCA data and methodology has allowed us to measure net CO<sub>2</sub> over the lifetime of the product in its primary application but then, via well designed degradation methods (i.e. biological, chemical, photochemical etc), over their future incarnations in other products. Additionally, new methods for repairing composites have extended their lifetime and further improved their LCA credentials.

Lastly, optimising the use of local supply chains has driven the carbon emissions to an optimised low.

#### Current State

Today we have some naturally derived polyols and there exist proven methods for making polycarbonates from CO<sub>2</sub> and there are even technologies that exist which suggest that carbon fibre can be made from lignin. Non-woven hemp and flax fibre are widely available and some products are well established, albeit at low volumes, in the automotive industry.

The supply chain for bioderived raw materials for the synthesis of new matrices is still quite immature, although materials such as succinic acid and furfuryl alcohol, both from sugar, are well established and the trend is for bioderived chemicals to increase in both variety and volume.

We have some basic composites recycling and some UK expertise in carbon fibre recycling at ELG Carbon Fibre but options for glass and also for value recovery from the matrix, other than for energy recovery, is underwhelming at present.

REACH is being used to drive changes in legislation and the public perception and negative reputation of "plastics" is driving innovation in our sector.

#### Path to Value

LCA standards, data and methodologies must improve, align and gain industry approval in order to gain credibility and drive their adoption and uptake across the composite sector. This will help us establish critical baselines on our current products whilst enabling us to make informed decisions on new raw materials, processes and production methods to minimise or reverse the damage we're doing to the environment.

A UK funded Circular Economy Consortium will be set up to drive these LCA improvements. A realistic, but challenging grace period for the composites industry will drive multiple development streams (fibres, resins, techniques, recycling etc) towards meeting legislated deadlines for the generation of excess CO<sub>2</sub>. The use of low carbon and even carbon free energy sources in combination with more efficient manufacturing techniques will take us further towards these goals.

## **A2: Establish bio and secondary resource supply chain**

*Tim Sweatman, Eco-Composites Ltd;  
Gary Leeke, University of Birmingham;  
Martin Wright, Polynt Composites EMEA*

### **Future Scenario**

A sufficiently wide range of feedstocks designed for the composites industry (i.e. raw materials for resins, resins, fibres, ancillaries etc) is available. These materials are both affordable and of consistent high quality. LCAs are available and well-defined demonstrating the reduction in waste (i.e. water, CO<sub>2</sub>, energy, effluent etc) and inherent benefit in using these over virgin petrochemical feedstocks. The feedstocks have been tested and approved for use in composites and meet the current quality standards. This has been made possible due to the increased tax obligations of converters who use virgin feedstocks and the establishment of processes for effective recycling, reprocessing and redistribution of composite waste.

### **Current state**

Landfill is still the most cost-effective way of getting rid of waste composites and the incentives for trying to use bio-derived products or recyclate are hampered by the high cost and the lack of standards (i.e. specified products in designs). There is also the concern over consistent quality for bio-derived materials with respect to seasonal variations.

Cost of raw materials is currently market driven and the demand for bio-derived or recycled materials is low which is reflected in the price, lack of standardisation, number of suppliers and cost. Furthermore, current LCAs are under developed with different databases containing inconsistent data for similar products so it is not easy for designers and manufacturers to make informed decisions on the best products to use to mitigate environmental degradation.

Lastly, composites can vary widely in properties (density, hardness etc) and there are no industry-wide methods for their identification (i.e. RFID). Further frustration exists in the limited availability of machinery suitable for the downsizing and re-processing of composite waste.

### **Path to Value**

We need to establish legislation to drive the development of sustainable supply chains and this can be bolstered through a changing public opinion of the need for these materials. This is currently being successfully progressed in the arena of single-use plastic where law makers and influencers (i.e. social and popular media) are working hard to make single-use plastic an anathema. If we can, in parallel, introduce taxation/legislation with developing public acceptance of a “cost premium” for more sustainable products we can be successful.

### **A3: Eliminating the use of toxic/hazardous raw materials for fire retardant applications**

*Malcolm Forsyth, Scott Bader Company Ltd;  
Bharat Gandhi, Filon Products Limited;  
Joe Carruthers, Composites Evolution Ltd*

#### **Future Scenario**

REACH and global harmonised regulation has banned the use of halogens, antimony and phenolics due to the dangers they present to manufacturers, consumers and the environment. This process was accelerated by public opinion and increasing environmental awareness driven, in part, by the zero ocean plastic campaigns.

Added value in fire retardant products is delivered by having bioderived fire retardant products, products which are recyclable at their end of life, products which are self-cleaning and largely maintenance-free.

This was achieved through innovations in chemistry, process improvements, aligned supply chains and effective non-destructive testing methods.

#### **Current State**

Phenolic and halogenated products make highly efficient fire retardant products and although alternatives exist, they are more expensive (intumescent), denser (heavily filled) and/or available from very restricted supply chains (i.e. single-sourced PFA resins). Also, pressure from the public is not currently present and the fire standards don't change according to any strategy but tend more to react to events (i.e. major fires).

#### **Path to Value**

Government (external) funding has to become available to allow/drive collaborative research to develop effective alternatives that meet the strictest criteria of safety and suitability. Armed with the results and appropriate data we have to engage with and enlighten customers to create the demand for alternatives. We also have to address the supply chain constraints, particularly on resins such as PFA (polyfurfuryl alcohol) by creating alternative and competitive suppliers.

We also have to lobby (Governments / Law makers) to drive fire tests and fire standards to become simpler, standardised and more reproducible. Furthermore, we must ensure that these standards are harmonised to a high level globally.

## A4: Composite materials passport

*Jaap van der Woude, EuCIA*

*Steve Fletcher, KTN*

*Graham Sims, National Physical Laboratory*

### Future Scenario

Composite materials in 2040 come with a set of IDs that give full information on their composition, background, end-of-life options and embedded energy. This will allow the consumer to make informed choices of what materials they wish to purchase. This information can be stored via barcode, QF, RFID or some other tag. The process will reference EN 16425<sup>6</sup> and the relevant information will be stored in a central database. This is analogous to the traffic light system that started to appear on all packaged foods at the beginning of the century describing fats, salt, sugars, calories etc.

Additionally, we will have a general repository that collects all OEM information that is accessible by recyclers. The OEMs maintain a parts inventory based upon this system.

### Current State

Recyclers have some general knowledge of OEMs materials however converters may be unwilling to share recipes. The performance of recycled materials are characterised by lowest possible outcome. Current recipes define the input materials. Some processors are also raw material suppliers.

### Path to Value

We need the EU to mandate a code on the recycling of composites. The benchmarking of “generic” formulas at the Catapult centres could be a prelude to this or perhaps a result of it. The code needs to take into account all of the current limitations of today (i.e. as highlighted in the **Current State** above).

A lot of work will have to go into the development of the validation and reporting system. We may be able to draw upon a finger-print approach rather than a barcode system as this seems rather rudimentary and something more robust may be more appropriate or required.

Following the development of the validation/reporting system, a project will need to be run to fully test the procedure and gain EU acceptance of the system.

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<sup>6</sup> BS EN 16425:2014 Simple Publishing Interface <https://shop.bsigroup.com/ProductDetail/?pid=00000000030260320>

## A5: No landfill for waste composites

Natan Elfassy, Agecko UK Ltd

Nigel Keen, National Composites Centre

Steve Newman, Vestas

### Future Scenario

In the future, legislation may require zero landfill in the UK or cost implications may rule it out. The future scenario envisages several potential alternative routes as an option for landfill, all of which exist now, though some only to a very limited degree, or not in UK. In order of value, high to low:

- The composite product or material is re-used as composite with limited or no processing.
- Fibres are recovered and resin is used as new material feedstock or for energy recovery.
- Material is otherwise recycled, e.g. by grinding, which may be downcycling, for 'right cost' material.
- The composite is burnt to recover energy from resin, but with no residue to landfill. In a cement kiln, the mineral content becomes part of the cement. In an energy from waste (EfW) plant, it can be recycled as aggregate. However there is a strong argument that EfW is not a good solution.

Product codes or a 'composite materials passport' help to find the best disposal / recycling routes.

### Current State

Currently it is thought that around 90% of FRP in UK goes to landfill and about 10% to waste to energy. Some wind turbine blades and boats are being repaired and refurbished for life extension, but very little composite material is being re-purposed. There is some recycling of carbon fibre, mostly in-process waste. The cost per tonne for landfill is about the same as for energy from waste. However, most UK waste to energy plants are only about 30% efficient in converting waste to energy (as electricity) and don't use the secondary heat energy. *Note: [FRP Circular Economy Study \(2018\)](#)<sup>7</sup> outlines the current state in more detail.*

### Path to Value

Understanding LCA impact of products, including different end of life routes is required to guide solutions. A mindset to design for re-use and recycling needs to grow and standards need to be developed for secondary materials, including LCA and design / performance data. Process waste reduction, such as net shape processing, reduced trim, 3D printed products is critical to saving cost, waste and environmental impact. More high profile demonstrators for high recycled content products will influence the market.

Legislative incentives for recycled content or re-use need to support a more circular future, e.g. sustainability tax credits. Several factors could lead to increased demand for secondary material, but markets need to develop to see that available at the right price with recycling processors in place. Product take back schemes and lease ownership can be enablers for that.

We need cost effective collection and logistics, which may include reverse logistics to deliver and collect, and effective, portable downsizing technology. Developing a materials passport system will help identify the best end of life / re-life solutions. If EfW is to remain part of the solution, then there needs to be an increase in efficiency of waste to energy plants, or we seek out and prefer those which recover secondary heat and recycle bottom ash.

Technical developments that could lead to higher value / lower impact solutions include improving pyrolysis to recover chemicals, chemical re-processing / refining of waste, reversible cross-linking chemistries so that the composite resins can be degraded more easily. Bio-composites, especially for bulk, low performance products, would lead to carbon neutral energy recovery at end of life, or possibly even anaerobic digestion.

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<sup>7</sup> <https://compositesuk.co.uk/industry-support/environmental/end-life-and-recycling>

## **A6: Circular economy business models**

*Paul McCutcheon, University of Exeter*

*Olivia Bertham, Oakdene Hollins*

*Peter Garrett, Vestas*

### **Future Scenario**

In this future scenario, producer responsibility for waste is required by regulations, so business models have been created to support a more circular economy. Optimally there is fully closed loop recycling, though maximised cascade (downcycling) through loops provides a realistic alternative for some materials.

Business models include more leasing contracts and/or a move to servitisation. Servitisation involves delivering a service component alongside the product, to maintain through life quality and value, e.g. including maintenance and retaining the product connection for take back at end of life. These are enabled by strong design for circular economy principles and improved recycling technology.

### **Current State**

Some sectors are already seeing a trend to increased service / lease models. Some companies already have take-back schemes for composite products (e.g. roofing sheet). When wind farms are constructed, bonds are often purchased to cover disposal at end of life.

Currently markets for materials are uncertain and can be volatile. Materials have minimal value at end of life. There is a lack of commercial options for reuse / recycling. This is driving an increased trend to thermoplastic composites.

### **Path to Value**

Target sectors for such approaches need to be defined, e.g. automotive and aerospace may be easier than construction and electronics. Materials need to be valued throughout the life cycle. This links to public perception which needs to change, such that people see value in end of life materials and products and don't just throw them away.

Financial incentives are needed, e.g. tax breaks for recycled product, moving to an expectation for companies to disclose recycled content of products. This links to the materials passport concept which would provide traceability.

Investment in technology innovation for material or product re-use is needed, requiring a radical review of design selection of materials and processes. Material standards and specification for secondary materials are required to enable this.

Finance models will need to change, internalising resource cost, e.g. up front or through life cost will need to allow for costs of degradation and acknowledge natural capital impact, i.e. impact on the economy of natural resources that sustain us. Financing could include circular economy bonds.

## **A7: 100% recycled, 100% recyclable composite parts**

*Steve Pickering, University of Nottingham*

*John McQuilliam, Prodrive*

*Frazer Barnes, ELG Carbon Fibre*

*Sheena Hindocha, KTN*

### **Future Scenario**

In 2040 all composite materials will be produced using sustainable materials and energy. It will be possible to recycle all composite materials once end of life is reached and all manufacturing waste will be recycled.

### **Current State**

Currently an insignificant amount of waste from composites manufacturing is recycled, production of composites using renewable energy has been demonstrated however this is not yet a viable option for the majority of composite manufacturers. Use of sustainable raw materials in the production of composites is low, due to cost of sustainable feedstocks versus standard feedstocks. The large majority of composite materials at end of life are disposed of via landfill, in some cases a waste to energy route is used.

### **Path to Value**

Industry incentives - The industry can be incentivised to move towards the aim by the use of regulation, legislation and schemes for both the use of renewable fuels in manufacturing and the responsible disposal of waste i.e. no landfill. This may include manufacturers being responsible for products at end of life.

Design for sustainability - The full life cycle of a part needs to be considered during the initial design phase of product development. This should include requirements for LCA, consideration of how products are disassembled and how parts are subsequently separated and recycled. This may require the use of a materials passport.

Development of market for recycled components - A valuable market for recycled components needs to be developed not just within the composites industry but external to the industry. Innovation in how to utilise recycled materials is required. Demonstration and validation of products and technology at scale once developed.

Development of sustainable feedstocks - Further innovation in the production of bio-based materials or sustainable production of precursors is required. This requires development of the industrial base in fibres and chemicals. The development of new feedstocks should consider the requirement to be recyclable and cleavable at end of life.

Development of zero waste manufacturing routes – New manufacturing routes require investigation to reduce the amount of waste during the manufacturing process. This may need to move into true 3D additive manufacturing.

### **Dependencies**

Key dependencies outside the composites industry which will need to be taken into account:

- Infrastructure is required to provide access to renewable energy sources
- Infrastructure for waste collection, sorting and re-processing

## **A8: Increase % of sustainable feedstock**

Steven Brown, Scott Bader Company Ltd;  
John Conti-Ramsden, Centre for Process Innovation;  
Stuart Coles, WMG, University of Warwick

### **Future Scenario**

The consumers of the future are bought in to ethical, social and environmental factors when making their purchasing decisions. Composites in the future will be composed of fully sustainable materials. Sustainable materials are recoverable in the value chain. Composite parts will be fully traceable from beginning to end of life through a regulated and auditable process, i.e. composites passports.

By 2040 all of our composite applications can be defined as being 100% sustainable in content.

We will need an integrated supply chain management tools specific to composites. We will have an established industry for the collection and repurposing of composite waste. We will have manufacturing capability for the use of recycled feedstocks and accepted, accessible and standardised LCA methodology and data.

### **Current state**

Currently we have no regulated standards for LCA. Cost and performance are key drivers, not environmental impact. Social attitudes are beginning to change. Currently less than 5% of content in composites is sustainable, in resins and non-synthetic fibres.

Glass fibre is low environmental impact, though it does use mineral resources and energy. Some chemical companies are putting sustainability at the heart of their strategies or using sustainability as a differentiator. These include Croda, Perstorp, BioAmber, Calysta.

Decarbonisation of electricity is occurring. There is a lack of understanding regarding LCA. Most of the supply chain depends on fossil fuels and petrochemicals. The knowledge base for science and scale up exists in UK. There are some well-established sources of biomass in places like Brazil and Scandinavia.

### **Path to value**

We need

- an incentive for companies to invest in sustainable technology development. For example more “Green” financing.
- to understand why companies aren’t using existing sustainable materials (e.g. PBS / bio PE).
- to look for applications where bio-based raw materials are chosen for performance benefits.
- Develop a UK bioeconomy roadmap (*note: UK Bioeconomy Strategy was published late 2018.*)
- to identify critical platform molecules (from wastes / bio) for materials / resins
- legislation to reinforce sustainable concepts and a framework for reporting sustainability
- demonstrator products for stimulating the supply chain
- more societal demand for sustainability

This will lead to major applications being identified and implemented.

## **A9: Hybrid smart, multifunctional multimaterials**

*Tim Young, National Composites Centre*

*Andy Clifton, Rolls-Royce*

*Lien Ngo, Innovate UK*

### **Future Scenario**

In 2040 there is substantial demand for fully integrated hybrid smart multifunctional material systems which utilise innate properties to provide performance increases, smart capability and functionality. This has led to the development of structural assemblies with integrated intelligent materials (incorporating sensors and systems) with secondary functionality such as electrical / thermal conductivity.

Societal pressure requires these complex material systems and their applications to be designed with end of life in mind. Government, corporation and the public avoid the use of multi-functional materials which are unsustainable and design decisions are based on LCA profiles with proven environmental credentials. Designs and application utilise the end of life waste streams through established routes for recycling, reprocessing, repurposing, up valuing and disassembly of these material systems.

The widespread application of complex material systems will not be achievable without the development of end of life approaches, applications, improved value stream mapping and life cycle analysis toolsets.

### **Current State**

Multi-functional materials are seeing an increase in demand to meet the need of future technology requirements. Hybrid systems incorporating polymer-ceramic composite with metallic wiring exist to provide electrical conductivity alongside semi-structural support. Embedded fibre-optics lie alongside glass and carbon fibres within the composite to provide mechanical and functional condition monitoring capabilities within applications such as subsea riser systems and bridge structures.

The increase in uptake of such systems is not currently limited by their lack of disassembly options. Hybrid composites (e.g. mixing carbon and glass within at least one resin system) and toughened resins (e.g. mixing thermoplastic and thermoset) present significant challenges in the inability to separate the system into their original systems. This is not helped by the lack of planning for end of life during the design stage, the limited options for discombobulation and the lack of application or value in the separated materials.

### **Path to Value**

Short term gains can be achieved through the development of advanced LCA techniques and value stream mapping for integrated versus assembled material systems. This will enable designers to make decisions based on sustainability data and identify the value of end of life options available.

Work is required to develop the material systems themselves to enable end of life solutions. Options include producing sustainable material chemistries which unzip and systems which can be de-joined or un-welded. This will enable more end of life options and enable a developing supply chain to source alternatives to raw feedstock. Further developments are required to handle material separation at end of life. We need data on the reclaimed material properties and improved LCA case studies coupled with established applications for repurposing the material or the separated material.

Immediate work is required to create publicly available LCA data for reclaimed and raw material feedstock as well as the impact from the multitude of processing options. Parallel activities are required in the development of material chemistries. Applications for future product could be influenced through the creation of targeted case studies.

The creation of a talent institute or Catapult Centre for Sustainable Materials would help to drive this and also give a platform where academia, manufacturers and end users could gather together for collaborative research, leading to pre-products, testing and eventual adoption.

## A10: Composites as go to material for mobility

*Stella Job, Composites UK*

*Marcus Henry, Jaguar Land Rover*

*Steve Barbour, Composite Braiding Ltd*

### Future Scenario

By 2040 for composites to be a 'go to' material in mobility, we will have gone through another intermediate generation of vehicles (c 2030) where composite use has increased, usually replacing metallic parts, leading to the 2040 generation where there is widespread use of composites as standard materials, used optimally in mainstream automotive and other areas of transport.

By this stage we expect there will be 'standard' grades of composite with associated design datasets. Accepted standards for whole life impact will be in place. The structure will be recyclable, with clearly understood options for Repair vs Replace vs Re-use vs Re-purpose.

Fully competent UK (local) 'just in time' supply chains will have cost-effective production capabilities including cheaper tooling, linked to new business models requiring less upfront capital; highly automated, near net shape manufacturing; fully understood multi-material combinations and joining, etc.

### Current State

Currently we know how to generate data but have too much secrecy. There are no standardised widely available datasets. Likewise CAE/CAD methodologies not standardised. There is limited LCA capability & standards but increasing environmental focus. The supply chain is still fragmented and immature but there is clear auto demand for higher volume, lower cost.

Applications and demand are growing in niche/high end auto and the development process for higher volume and more automated processes is under way. Notable capability exists at AMRC, NCC, WMG. The UK supply chain needs to be developed – we have carbon fibre (SGL in Inverness) and glass fibre (NEG in Wigan) manufacture, but the majority of that is exported while we import what we use. Use of pyrolysis recovered carbon fibre is growing, but volumes will not match substantial applications in mainstream automotive.

### Path to Value

The primary areas to be addressed are:

- Data – standardised data (CAE/CAD/materials/LCA) is required and should be available to the same extent as it is currently for metals. This is a key early action.
- Automated Processes – are required to be developed for high volume, cost effective composite components to be realistically available. A UK supply chain to deliver these processes is essential. The Catapult centres should play a bigger role showing the 'art of the possible' through high profile demonstrators.
- Tooling – developments to support lower cost, near net-shape, high volume composite components is required.
- Sustainability – we need clear re-purposing/recycling/re-use options and a supply chain to match.
- Multi-materials – are the future. We need to work with other sectors to optimise use of composites where they add value alongside other materials.
- Materials – keep developing the material capabilities e.g. new fibres, new matrices. Increased use of thermoplastic.

## **B1: No unsustainable fossil fuel derived ingredients**

*Tim Sweatman, Eco-Composites Ltd*

*Steve Pickering, University of Nottingham*

*Peter Garrett, Vestas*

### **Future Scenario**

By 2040 it will be unacceptable to use fossil fuels or any other unsustainable materials in the production of composite materials. This implies:

- All the energy used in the production of materials (fibres and resins) and during manufacture of components will come from sustainable sources, which could include electricity generated from renewable sources or the use of biofuels.
- All materials used will be from sustainable sources. For examples, polymers will be derived from biomaterials or other sustainable sources.

### **Current State**

The current situation is far from sustainable. In terms of resins, almost all of these are derived from petroleum and use fossil fuel to manufacture. All carbon fibre is currently derived from fossil fuel feedstock and most of the energy needed to convert the raw materials to carbon fibre is from fossil fuel. Although some carbon fibre is manufactured from PAN using renewable electricity (eg SGL's plant in Washington State in the USA, where hydroelectricity is used). Glass fibre is manufactured using fossil fuel fired furnaces. A limited amount of natural fibre is currently used for composites. Composites manufacturing operations currently use much fossil fuel derived energy for electricity and heating. Currently though there are no real incentives to move away from fossil fuel derived materials.

### **Path to Value**

Drivers are required and these could include financial or legislative incentives to move away from fossil fuels, and the availability of plentiful renewable energy.

The key step along the path is to invest in research and development of fibres and resins which are based on sustainable resources and the highest priority area here is carbon fibre. Currently there are no carbon fibre materials that can give the performance of CF based on petroleum precursors, despite research in recent decades into biobased precursors such as lignin. This is a priority area.

Bioresins are under development and there is the technology now to produce these from sustainable sources, but more work is needed to develop these further and make them more economically viable. A potential barrier to the use of biobased materials is competition for land area.

An essential requirement is to develop the quality standards and certification required for these new fibres and resins from sustainable sources.

A potential barrier would be if costs of these sustainable materials were too high relative to other materials and there were no other incentives to move away from fossil fuels.

## **B2: Repurpose manufacturing waste back into process**

*Richard Diskin, CUBIS Systems*

*Bharat Gandhi, Filon Products Limited*

*Paul McCutcheon, University of Exeter*

### **Future Scenario**

In 2040, composites will be manufactured with zero waste as we have found secondary applications for waste materials and new ways of re-using or eliminating the need for ancillary materials which used to be considered single-use items. To support this, equipment and processes designed for the recycling of composite waste have been developed and are readily affordable. All of this leads to well-established supply chains for waste primary material and also markets set up to consume them.

### **Current State**

Landfill costs for composite waste are increasing and in some parts of the globe, composite waste is banned from going to landfill. There are some outlets such as cement kilns and waste to energy but the cement kiln option does not exist as a formally recognised scheme in the UK. There are options for recovering carbon fibre from waste CFRP but thus far this is not financially viable for glass fibres. Also, the markets for using re-purposed composite waste are somewhat limited and the technology has limited commercial viability.

### **Path to Value**

A critical step is the identification and valuation of the markets for secondary composite waste material and these markets should not be limited to composite markets as that will limit our thinking and our options. We also need to research and gather (and distribute) data for the use of recycle in new products. Legislation to push converters to use recycled material or government subsidies for those who actively engage/research in this area will help drive this forward.

Companies need to invest in product design and provide us with affordable new technologies for materials that are easier to recycle and we also need to invest our efforts in working towards new manufacturing processes to support zero waste (i.e. next generation additive manufacturing for composites).

Lastly, the composite industry should engage with other industries where waste is generated to understand and evaluate other forms of secondary materials that might find a home in new composite designs and products.

### **B3: Develop applications for recovered material**

*Stuart Coles, WMG, University of Warwick*

*Nigel Keen, National Composites Centre*

*Jaap van der Woude, EuCIA*

#### **Future Scenario**

Bulk, high volume applications for recycled materials exist and have replaced traditional composites; examples of this include alternatives to timber and use in Portland cement. We have linked circular economy loops with waste and end-of-life composite materials and established business models for the recycling of composite materials. This has led to zero landfill waste and 100% recovery of composite materials.

#### **Current State**

As it stands, virgin raw materials are readily available, of high quality and low cost which is in stark comparison to secondary raw materials where variability of recyclate is high. There are routes to recovering fibres from composite waste such as pyrolysis and chemolysis however this is only really financially viable for carbon fibres. Recycled short carbon fibre is available in various formats (non-woven mats, milled fibres and chopped tows) but not as yarns. Furthermore, there has been no demonstrated use for the matrix of waste composite other than a source of fuel.

#### **Path to Value**

We will begin by investing in composite sector applications for waste composite materials. Directives and legislation for the amount of recycled content in new products will help drive more research in to this area. This will then drive a move towards an increase in modular and/or prefab composite constructs.

Greater understanding of how we assess and measure the benefits of sustainability (i.e. financial drivers or suitable LCAs) will drive the demand for secondary and end-of-life materials to re-enter the raw material value chain. The materials passport will give consumers and converters confidence in the use of these recovered products and allow them to make informed decisions.

## **B4: Prefab construction**

*Stella Job, Composites UK*

*Graham Sims, National Physical Laboratory*

*Joe Carruthers, Composites Evolution Ltd*

### **Future scenario**

By 2030 we envisage the widespread use of composites with high bio/recycled content and low manufacturing energy, leading to a more sustainable solution for pre-fabricated parts. These structures will be light weight, enabling quick, low cost installation. They will provide excellent thermal insulation and fire performance. Applications could include:

- cabins for cruise ships
- bridges
- buildings such as housing, schools, offices
- lightweight disaster relief buildings (probably more morgues / hospitals than housing, as housing generally uses tents / local materials)

Underpinning the widespread acceptance will be the completion of relevant standards, the availability of standardised material grades, harmonisation of tests for building regs / IMO regs, etc. A supportive government procurement policy will drive adoption, leading to asset owner acceptance.

By 2030 we see that business models will consider through life cost and capability to design with composites will be widespread, including joining and integration technology. Sustainably sourced raw materials will be available and parts will be designed to be disassembled for re-use or recycling.

### **Current state**

Currently the “bricks and mortar” mindset in UK reduces acceptance of non-traditional builds and affects insurability and mortgageability. However the housing crisis drives the need for quick-to-erect buildings, so there may be potential for leveraging government support for composite houses. There is some manufacturing activity in UK in this area, and it is increasing, but we are still predominantly importing pre-fabricated bridges and houses.

While the design capability exists, standards are lacking. A Eurocode (for structural and fire performance) for composites is under development. Material and fabrication costs of composite solutions are often higher and while in many cases composites can reduce through life costs, finance tends to be too capex focused to benefit. There is a lack of ability to incorporate recycled materials.

### **Path to value**

The path is less about technology and materials, more about acceptance, standards and business models. Thus a primary focus needs to be to complete the Eurocode and develop standards.

Developments which will enable cost reduction include automation (reduced labour costs to compete) and modularity and/or high volume production. More modular means more market opportunity. Incorporation of recycled materials can also reduce cost, and needs development, noting that some primary structural applications may not be appropriate for recycled materials. Bio-content can improve acceptance because of “green” credentials, and in some cases results in lower VOCs, improved insulation and improved fire performance.

The performance improvements inherent in composites need to be demonstrated. These include thermal, acoustic, weight reduction, durability and corrosion resistance. Low maintenance is especially important for bridges (though “bricks and mortar” houses are extremely durable). Greater performance leads to higher prices, and effectively multifunctionality, e.g. where the structure does not need separate insulation. Cost-effective fire resistant / low FST solutions need to be developed and demonstrated.

## **B5: Zero waste, zero tooling manufacture**

*John McQuilliam, Prodrive*

*John Conti-Ramsden, Centre for Process Innovation*

*Lien Ngo, Innovate UK*

### **Future Scenario**

The goal is to produce a sustainable tooling system which would be in the form of a tool-less processing or sustainable tooling. As part of this objective the sustainable tooling should be re-useable and recyclable.

The driver for sustainable tooling is high cost, long production times and mismatched coefficient of thermal expansion (CTE) in single sided and matched tooling. Current tooling is produced from either metallic or polymer composites from raw materials not from sustainable sources. This tooling has low thermal inertia and as a result one of the drivers is to select materials which could heat and cool quicker, reducing the energy consumption during processing.

Polymer composite tooling is simple to produce using the tools available in composite workshops however, they possess a limited life span minimising the reuse in large-scale production.

### **Current State**

Current tooling systems are either “hard” metallic or “soft” polymer composites. Metallic systems are typically formed via subtractive machining; these are usually steel or Inconel or steel with an Inconel coating. Soft tooling is made with standard reinforcing fibres, typically glass or carbon fibre with a specialist synthetic tooling resin, which cures at low temperatures 20-80 °C with in-service temperatures of 120-250 °C. Developments in soft tooling have included self-heating for out of oven curing enabling rapid cooling.

Additive manufacturing has also been shown as a method for low use prototyping tooling.

### **Path to Value**

The path to produce these goals includes the part/laminate geometry and materials processing data which can enable sustainable tooling development. Next steps are to investigate adaptive tooling with thermoplastic, reformable thermosetting and bio derived matrices.

## **B6: Value chain based on rented / leased composite materials**

*Clive Williams, Scott Bader Company Ltd  
Marcus Henry, Jaguar Land Rover  
Martin Wright, Polynt Composites EMEA*

### **Future Scenario**

In 2040 there are fully developed methods for recapturing value from the majority of composite parts at their end-of-life. The fibres can be recovered and the organic content from the resins / adhesives are viewed as valuable sources of future raw materials or, at worst, fuels. With so much value embedded in the parts, the manufacturers have developed value chains on the leasing of composites where the user returns the part to the manufacturer, rather than be liable for its disposal and the manufacturer is able to valorise this towards future sustainable products.

The innovative lease model allows customers to spread the cost of the part over its lifetime, reducing their initial investment whilst also providing the part manufacturer with a continuous revenue stream.

### **Current State**

Currently this model does not exist for composites but in recent years it has been adopted across a variety of industries such as media, fashion, textiles (i.e. carpets), steel and transport. This model has disrupted the industries where it has been successful (i.e. Tata Steel, Interface Flooring) and in some cases made redundant the traditional models (i.e. Netflix, Spotify).

There are some examples of businesses that are willing to take composite waste and use it as a value material. This can range from things like waste-to-energy or conversion to clinker in cement furnaces all the way through to companies who reclaim carbon fibre from waste composite (ELG Carbon Fibre) or convert waste plastic to new plastic (SABIC).

### **Path to Value**

We first of all have to identify a product that could use this concept and prove that it could work in a business context. This would need to be demonstrated as being both practically and financially feasible. Interface Flooring is already doing this and we should consult with them to understand what the challenges were (or still are) and how they overcame them.

Tractability and easy identification of the component part (i.e. composite passport) will be required to allow this to become a reality. Tata Steel, who currently lease steel for construction projects, often receive steel back at their site which did not originate from any of their factories, so this is key to making this work.

An infrastructure for the collection, identification, storage and revalorisation of the waste needs to be established along with incorporating designs which allow for easier disassembly at their end-of-life. Finally, legislation (punitive or incentive or both) to restrict the use of virgin raw materials and the mining of new precious minerals will help drive this type of model to replace the established way of doing things

## **B7: Cost-effective bio-based thermoplastic**

Steve Fletcher, KTN;  
Steven Brown, Scott Bader Company Ltd;  
Steve Barbour, Composite Braiding Ltd

*(Note: this group chose to focus on high performance thermoplastics as lower performance thermoplastics such as PLA are already widely available.)*

### **Future Scenario**

In 2040 the idea of using petrochemicals to make materials such as these will be treated with scorn. Instead we will have bio-based thermoplastics with high PEEK-like performance (i.e. temperature, toughness). These can either be synthesised from biomass or they can be obtained via industrial biotechnology (i.e. grown/biosynthesised and extracted). Added value is achieved where the materials have easy repair or self-repairing capabilities. All resins will have an LCA profile that proves their environmental credentials.

None of the above will be achievable unless we have strong bio-engineering capabilities, ability to produce at large scale, a strong supply chain and a realistic cost.

### **Current State**

There are some examples of bio-based thermoplastics such as PBS (polybutylene succinate), PLA (poly lactic acid) and PE (polyethylene from sugar biomass) however these are relatively low performance materials in terms of toughness and temperature performance.

Petrochemical thermoplastics are currently used in pultrusion, extrusion, compression moulding and 3D printing applications. This comes with a variety of processing times and the products have a wide array of properties, however this is not reflected in the bio-derived options. There is no UK supply chain for high performance bio-based thermoplastics.

Thermoplastics are inherently recyclable (via melting and re-forming) and recycling supply chains exist for purer streams of waste thermoplastics, but it is often not easy to separate waste streams automatically and efficiently.

### **Path to Value**

We need UK development of high performance bio-based thermoplastics as this supply chain is missing. In order to achieve this, we need to set out our definition of “bio-based” and what credentials we use to determine if something is bio-based or not. We should also compile a list of the top 10 sources of biomass suitable for making materials from using UK capabilities and this should be shared with BEIS to drive support for this endeavour (Department for Business, Energy and Industrial Strategy).

The creation of a Catapult Centre for Materials would help to drive this and also give a platform where academia, manufacturers and end users could gather together for collaborative research, leading to pre-products, testing and eventual adoption.

## **B8: Developing new / emerging recycling technologies**

*Sheena Hindocha, KTN*

*Gary Leeke, University of Birmingham*

*Frazer Barnes, ELG Carbon Fibre*

### **Future Scenario**

In 2030 all composites will be produced responsibly with an understanding of segregation and component identification. All manufacturing waste and end of life parts will be recycled.

### **Current State**

Currently there are limited industry incentives to move to recycling parts in part due to the lack of commercial viability of recycled materials. A cement kiln process has been proven however kiln owners are very specific on the material which is accepted. Solvolysis techniques are currently only at pilot scale as are recyclable resins. Disassembly of large structures and preparation for recycling is also expensive and time consuming.

### **Path to Value**

Industry incentives - The industry can be incentivised to move towards the aim by the use of regulation, legislation and schemes for the responsible disposal of waste i.e. no landfill. A more integrated supply chain with a code of practise could be considered. Common LCA and material passports may enable end of life recycling.

Development of thermoset and thermoplastic technology – Alternative thermosets and thermoplastics which can be separated from fibres in different ways and allow for easier end of life processing. The sustainability of production and reuse and end of life needs to be considered in development as part of the design for sustainability.

New recycling method development – Collaboration between academia and industry to develop new recycling methods which have the capability to accept different material types. Access to funding and infrastructure to demonstrate new recycling methods which could be applicable to different industries.

Development of market for recycled components - A valuable market for recycled components needs to be developed not just within the composites industry but external to the industry. Innovation in how to utilise recycled materials is required. Demonstration and validation of products and technology at scale once developed.

New methods for disassembly – New routes to disassembly of large structures to enable recycling of materials. Design for sustainability should take disassembly into account and it could be aided by the development of new thermoset and thermoplastic technologies.

### **Dependencies**

A key dependency outside the composites industry which will need to be taken into account is infrastructure for waste collection, sorting and re-processing.

## **B9: Design for sustainability**

*Natan Elfassy, Agecko UK Ltd*

*Tim Young, National Composites Centre*

*Malcolm Forsyth, Scott Bader Company Ltd*

### **Future Scenario**

In 2040, LCA data exists for all composite building materials and processes (i.e. resins, ancillaries, fibres, techniques etc) and this data has been validated by cross industry representatives and is standardised and consistent across all databases. We have proven end of life (EOL) solutions for our products in applications as EOL is included in our design tools to support a fully closed loop life cycle.

All of this is underpinned by clear enforceable policies and standards on sustainability which we can assess and make decisions against.

### **Current State**

There are few products designed for sustainability. Some companies use sustainability as a unique selling point (USP) although this is viewed as an optional extra and is not essential. Furthermore, it is not currently viewed as a requirement by industry leaders.

At present we have no way of tracing composite component parts (i.e. constituent raw materials) from construction through to disposal (i.e. “composite passport”).

### **Path to Value**

We need to be able to agree upon the definition of sustainability to begin with and have this standardised and accepted across the industry to give us something to aim towards. Being able to categorise parts with a sustainability index (i.e. 1 – 5) could be very beneficial and simplify the design and decision making process.

We need to create a sustainable design demo which is fully costed with a clear message about the benefits with particular respect to EOL (end of life). Prodrive Composites have suggested that they could help with the design and the manufacture of demo parts.

An LCA comparison of recycled vs virgin feedstocks needs to be compiled using trustworthy data. This will help drive the process and help identify applications and markets for these materials. Furthermore, it will help drive new value chains for recycled or secondary raw materials.

Designs for closed loop manufacturing need to be established and be made widely available. Legislation will tighten controls on manufacturers for products / materials that do not meet the criteria for sustainability, whether this is at the beginning or the end of the life cycle.

Products must be made that allow for easy separation of components parts. Not all parts of the composite will be identical and different routes for their re-valorisation are required.

## **B10: Design for disassembly and value recovery / reuse**

*Olivia Bertham, Oakdene Hollins*

*Peter Wilson, WMG*

*Steve Newman, Vestas*

### **Future Scenario**

In 2040, composite articles are re-used many times and designing for the circular economy has become standard practice. This has been driven and enabled by designs which are led by well-established and accepted LCA data. Additional factors that enabled this change include:

- Standardisation for manufactured parts and panels
- Composites which are inherently reformable
- Traceability of composites composition all the way back up the composite part value chain
- Smart CAD (standard parts and database of secondary parts)
- A shift in ownership such that the manufacturer pays for end of life costs, not the customer

### **Current State**

Currently there are ways of remoulding short fibre reinforced thermoplastics but the ability to incorporate long fibres or do anything with thermosets is unavailable.

At present there is no legislation or economical business case to build disassembly potential into composites and no available designs for composites disassembly however it should be recognised that this may be set to change for white goods and electronic consumer goods (i.e. phones) where reparability is set to become an inherent design feature to reduce landfill and strain on precious supply chains.

### **Path to Value**

There is a requirement to build some infrastructure and data to make this a reality such as building in traceability for composite materials back up the value chain (i.e. raw materials, resins, reinforcements etc) and a central database for waste materials suitable for re-use in composites (or other products). Following this, or in parallel with this, pilot projects need to be executed to demonstrate the possibilities and help create markets for second-hand composites. Success here will allow us to train the designers and create new standards and codes for the joining of composite parts/structures. This will, of course, need to balance ease of disassembly with robustness in service and may require us to continually monitor the condition of our products in use.

Thermosets are viewed as particularly problematic for success in this area however banning them is not viewed as a universally approved option however instead we need to look at the whole LCA as well as considering next generation thermosets which are designed for value recovery.

## Appendix G: Pework - Vision Perspectives Summary

Collated responses from participants (not ordered or edited)

<b>Drivers + Market (customers/competitors) + Business perspective</b>	<b>Sustainable Application, Product/Service perspective</b>	<b>Capabilities, Science and Technology Resource perspective</b>
<i>Example: The UK economy has a drive for increasing self sufficiency</i>	<i>More secure supply chain through the use of sustainably (bio) derived materials</i>	<i>For example, Hemp exports could be diverted to providing a useful source of fibre and lignocellulose</i>
Adoption of circular economy thinking and policies	Opportunities for sourcing composite fibres and resins from secondary raw materials (including end of life composites)	Reduced resource extraction, reduced waste disposal
GRP waste volumes will continue to increase with landfill becoming increasingly unfavourable (availability/cost)	Waste diverted from landfill + energy/raw material(s) recovered from recycled GRP	Light duty parts can utilise recycled GF's recovered from GRP waste using the pyrolysis process
The transition to a circular economy puts pressure on the composites industry to provide end of life solutions	Transparent supply chains and formulations moving towards the use of renewable raw materials.	Efficient use of resources from secondary and renewable feedstocks with a plan for reuse or recovery at end of life
Environmental considerations will hold more relevance and importance in decision making	Local supply chain will be prioritised/preferred	Waste may become a commodity in all of its forms as a fuel source which rivals recycling rebates
UK composite sector: Decarbonisation to mitigate climate increase of 2C	Electrification and renewably powered production for raw materials and products	Lower temperature processing and technology conversion
Wind industry: Perception risk of blade waste arisings and disposal	Industrial reuse/recycling processes for resin, GF and CF	Technology for useful disassembly and conversion of thermoset resin waste to useful products
The UK transport market is transforming into an electric based "rent and recycle" model	Ultra lightweight structural components which can be disassembled and re-used with significant increase in lifespan.	Development of hybrid structures using a combination of materials and technologies in combination with "smart" adhesives
Circular Economy (potential) EU legislation & anti-plastic sentiment	Use of sustainably derived raw materials	Performance and cost parity with oil-derived raw materials
The building industry regulations requires enhanced fire performance products	New translucent resins necessary to achieve higher fire performance	Resin industry in conjunction with composite manufacturers to develop new products
Lightweighting especially for longer range Electric Vehicles and Aircraft	Can anthropogenic resources be utilised to secure supply	Development of new chemistries that facilitate re-use and disassembly. Determine LCA of any new materials
End of Life Vehicle regulations	Recyclable composite car body panels	Using reactive thermoplastics to reduce the cost of producing low volume recyclable thermoplastic parts.

Single use plastics are unacceptable (either socially or legally)	Any product containing plastic must be capable of re-use, recycling or reducing other wastes e.g. longer life	Fully functioning supply chain using Industry 4.0 electronic BOMs to effectively manage plastic wastes
The construction industry require LCA and durability data prior to investing in Composites	Composite classifications standards for material groupings with validated datasets	LCA data generation for fibres and “popular” materials coupled with the variation in processing routes
Market preference for sustainable “green” products Drive to re-use or recycle materials at end of life	Composites designed for a range of end uses in transport, energy, construction etc.	Re-use and recycling of polymers and fibres reduces demand on virgin material
The UK wishes to maintain its position as a leading innovator in composites	Exploit the performance advantages of bio-derived materials to provide new or enhanced functionality	For example, improvements in fire performance, lightweighting, vibration damping, cost reduction, recyclability, aesthetics
- Composites unlike metals offer step change in vehicle body structure stiffness at lighter weight - Stiffness = refinement - Affordability in line with weight saving value - Vehicle weight below 3500Kg for category B licence Manufacturing process can enable significant part count reduction over current solutions	Tier 1 Manufacturing processes to be near net shape thus near zero waste from UK source. Life Cycle Analysis to answer. PAN route first.	Catapult centres to identify barriers to entry and address for UK benefit. German solution = MAI carbon Alternate fibre materials to have costs / CAE data cards available to facilitate adoption
Governmental policy, legislation and consumer pressures to find a solution to end of life composites	Recycling and recovery of fibres, or reuse of fibre reinforced products	New second life markets needed, with refined recovery processes, and robust supply chains
UK economy moves to a fully sustainable future.	Composite materials are fully sustainable throughout their lifecycle.	Carbon fibre can be made from sustainable materials.
Thermoset polymer usually will be burnt at end of life	Increase bio-content in resins to reduce CO2 emissions	Research / investment to increase bio-content, e.g. 80% by 2030, 95% by 2040
The UK economy targets high value/high productivity portions of supply chains	Develop and scale up methods for recycling and reuse of mixed materials	Catapults will continue work with; think about other, non C fibre, composites.
Consumer drives lead to governmental pressure to label footprint impact on all products which will include a circular economic impact on end of life	Degraded products feeding back into the raw material pipeline, as fit for purpose, is recognised as more important than high performance	Product development is in line with degradation methodology such as polymeric material made in line with enzymatic degradative strains which produce safe “compostable” material to return to land use and/or materials to be utilised within the circular economy

<p>Customers are looking for sustainable alternatives but only bespoke and products where the natural and sustainable can demand a slightly higher price. Many potential customers are not aware of the natural composite replacement from traditional material technologies. The way to change many industries is through incentives or legislation,</p>	<p>Bio derived materials are available but there needs to be some initial financial support as currently small scale samples and small volumes make an expensive alternative. When a need is identified a better sourcing directory needs to be in place. Identify what industry would support sustainable alternatives and has the drive and cash to support it this would also secure the supply</p>	<p>The UK could be a good source of hemp as it grows well in many areas. Financially supported natural fibre and natural resin events to make people aware of the potential. An investigation activity needs to be run and be fully supported to identify what is available and what needs to be sourced and developed to meet customer requirements and demands in the future</p>
<p>Latest assessments indicate that Co2 emissions need to be significantly reduced by 2040 to avoid catastrophic climate change</p>	<p>Increased demand for composites as a structural material to light weight a wider range of transport modes and thus improve efficiency/suitability of electrification</p>	<p>Improvements to the Life Cycle of composites to further reduce their environmental impact with associated enhancement to the articulation of the benefits (and any remaining gaps) as part of a more integrated approach to creating a sustainable society</p>
<p>Consumers demand no disposal by land-fill or burning and 100% producer responsibility for end of life management</p>	<p>All products supplied must be able to be fully re-used or recycled at end of life, with no negative sustainability impacts</p>	<p>Fast-growing crop species needed which can provide both the resin/chemical and fibre needed for composite products</p>
<p>Composites are enabling and/or compete with other materials for the well-known reasons. Understand and use/position drivers (see attachment #1 over)</p>	<p>Understand full life cycle and increase awareness. End of use/life is often due to system failure, not composite</p>	<p>Consortia for development of applications and understanding of LCA aspects: academia, industry, Government working together.</p>
<p>Wind and pleasure boat applications are enabling, automotive is a mix as to the use of composites. Understanding cost as well as #2 are essential</p>	<p>Communicate a proper understanding of the full life cycle of composites and that EoU/L is a minor issue due to the overall advantage (see attachment #2)</p>	<p>Several examples in UK of good institutes UoN, NCC, Strathclyde. Examples of consortia abroad (my limited knowledge): AZL, F-ICT</p>

attachment #1

# Trends/Drivers for Fiber Reinforced Composites

## Material Replacement & Enabling

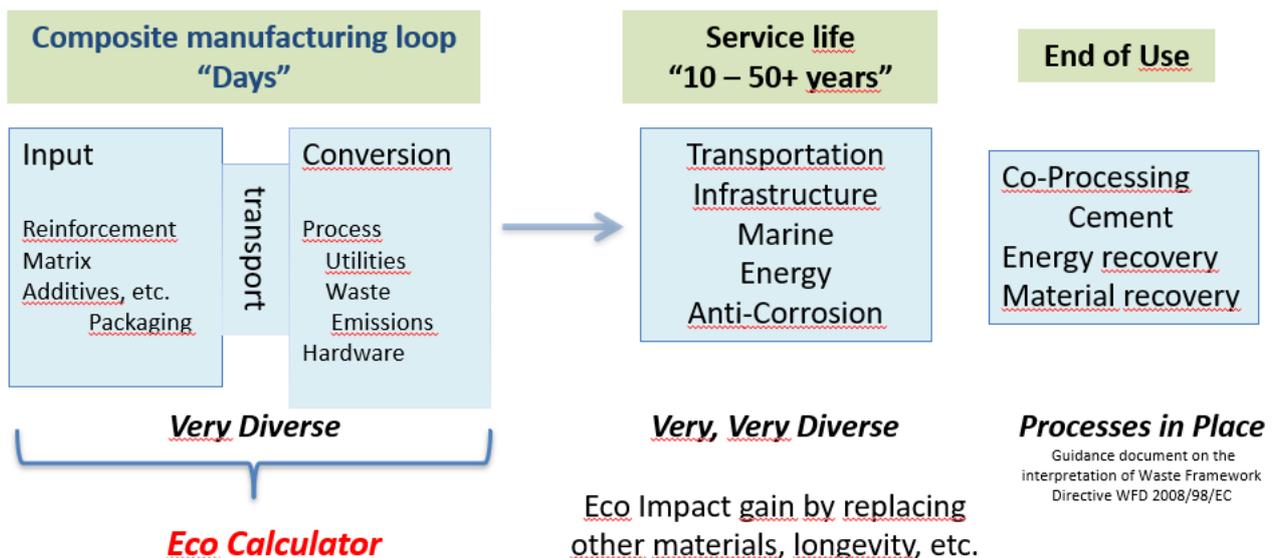
- **Economical & Performance**
  - Low weight
  - Installation costs
  - Chemical & heat resistance
  - Durability / Longevity
  - Maintenance
  - Freedom of design
  - Mechanical properties
- **Environmental & Societal**
  - **Climate change**
  - **Energy efficiency**
  - **Emissions**
  - **Sustainability**
    - Reuse, Recycle, Renew
  - REACH
  - Food & Water Contact

Understanding the Eco Footprint for full life use has become critical for material choices!!

attachment #2

# FRP Life Cycle

“Innovative Concepts: Many Different Products in Many, Many Different Applications”



EcoCalculator only for cradle to gate manufacturing: can be used as input for full life cycle calculations

